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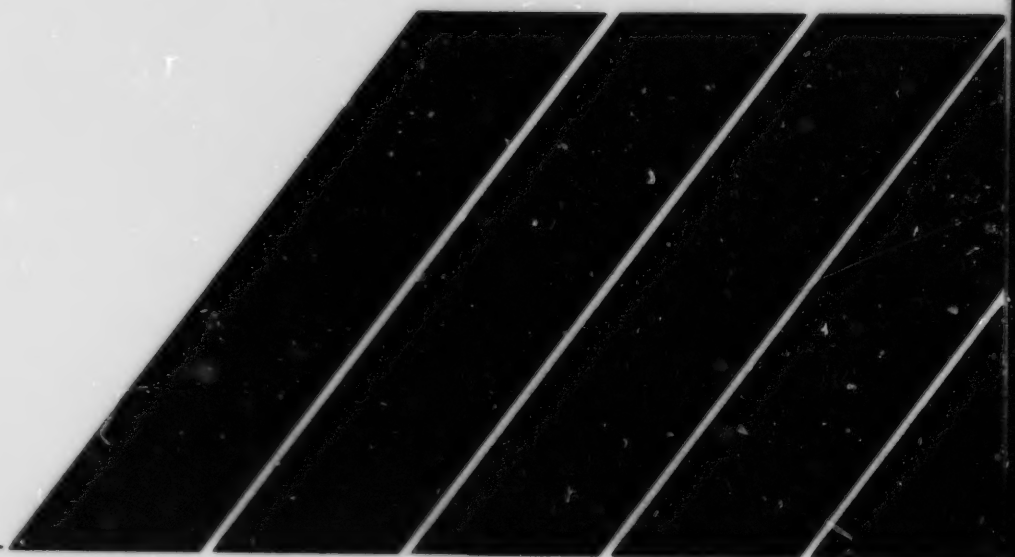
THE ATLANTIC WIND TEST SITE: A CENTRE OF EXPERTISE FOR WIND ENERGY RESEARCH AND DEVELOPMENT IN CANADA



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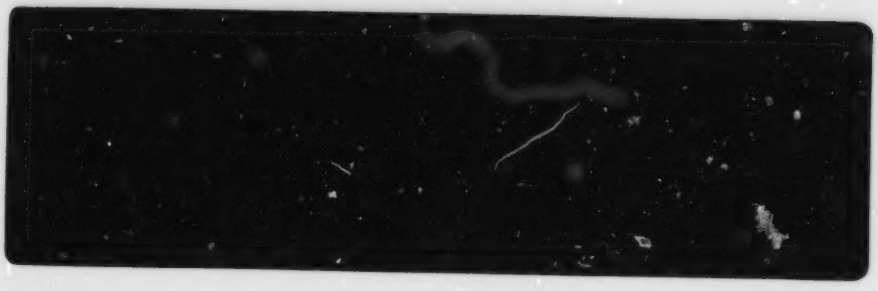

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ABSTRACT

The Atlantic Wind Test Site (AWTS) has provided assistance and information to the Canadian wind energy industry and community under the auspices of a Centre of Expertise Program sponsored by Energy, Mines and Resources through the Efficiency and Alternative Energy Technology Branch.

Since the inception of the program, the AWTS has been able to provide a broad range of technical, informational and promotional services both within Canada and abroad, through participation in international workshops and through its contributors to the development standards and guidelines for safe design and application of wind energy technology.

RÉSUMÉ

Le Centre d'essais éoliens de l'Atlantique (CEEA) fournit de l'aide et des renseignements aux utilisateurs et à l'industrie canadienne de l'énergie éolienne. Ce centre est exploité sous l'égide du programme du centre d'expertise exécuté dans le cadre du Programme de mise en valeur des énergies de remplacement du ministère de l'Énergie, des Mines et des Ressources. Depuis la création du programme, le CEEA est parvenu à offrir un vaste éventail de services techniques et de services d'information et de promotion au Canada et à l'étranger, grâce à sa participation aux ateliers internationaux et à sa contribution à l'établissement de normes et de directives quant à la sûreté de la conception et des applications de la technologie de l'énergie éolienne.

Créé en 1980, le CEEA sert de laboratoire d'essai et d'évaluation des nouveaux systèmes de conversion de l'énergie éolienne (SCEE) et de la technologie connexe. Ce centre a été mis en place par l'Institut de l'Homme et des Ressources dans le cadre d'une entente sur la mise au point des énergies renouvelables signée en 1977 par le Canada et l'Ile-du-Prince-Édouard. L'Institut est une corporation privée sans but lucratif qui se voue à l'élaboration et à la mise en application d'une technologie associée aux économies d'énergie et aux énergies renouvelables et à la recherche d'autres formes de production de nouveaux approvisionnements d'énergie durables et respectueux de l'environnement.

En 1981, l'Institut et le Conseil national de recherches ont signé une entente de 10 ans aux termes de laquelle le Centre serait exploité à titre d'installation nationale pour la mise à l'essai des SCEE à des fins de production d'électricité. En 1985, l'entente a été transférée à la Direction des énergies renouvelables du ministère de l'Énergie, des Mines et des Ressources.

Afin de répondre aux nombreuses demandes de conseils et d'aide en matière d'énergie éolienne reçues de l'industrie et du gouvernement, le Centre a proposé qu'EMR lui apporte l'aide requise pour fournir et diffuser les renseignements et offrir l'industrie ses services et ressources dans un contexte simple et efficace. Le projet a donc été approuvé, et les modalités ainsi qu'une définition des travaux admissibles ont été précisées dans un contrat signé par EMR et le CEEA.

Mis en oeuvre au mileau de juin 1986, le programme du centre d'expertise vise à aider la communauté oeuvrant dans le domaine de l'énergie éolienne. Renouvelé et révisé à deux reprises depuis son lancement en 1986, le Programme s'est révélé un moyen efficace et convenable d'aider la communauté et l'industrie canadienne de l'énergie éolienne.

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A - First Annual Report for the Centre of Expertise for Wind Energy Research and Development in Canada. AWTS Report 071, June 30, 1987.

B - Helio-Beauce Performance and Operational Evaluation

C - MBB Monopteros Description

D - MBB MON 15 Performance and Operational Evaluation and Significant Events Log

E - Parallel Generation with Wind Turbines - Technology and Experience, presented at the Canadian Electrical Association Conference in Vancouver, B.C., March, 1987.

F - Section 6.13, Chapters 8 and 9, prepared by the Atlantic Wind Test Site for inclusion in the IEA handbook Wind-Diesel Guidebook, Siting Technology and Implementation.

THE ATLANTIC WIND TEST SITE
A CENTER OF EXPERTISE
FOR
WIND ENERGY RESEARCH AND DEVELOPMENT IN CANADA

INTRODUCTION

The Atlantic Wind Test Site (AWTS) was established in 1980 as a laboratory for testing and evaluation of emerging wind energy conversion systems (WECS) and related technology. It was established by the Institute of Man and Resources (IMR) as a project of the 1977 Canada/P.E.I. Agreement on Renewable Energy Development. IMR is a non-profit private corporation dedicated to the development and implementation of renewable energy and energy conservation technology and other measures toward sustainable and environmentally sound future supplies of energy.

In 1981 IMR entered into a ten year agreement with the National Research Council to operate the Site as a national facility for testing WECS for electrical generation. In 1985 the agreement was transferred to the Department of Energy, Mines and Resources (EMR) Renewable Energy Branch.

In response to many requests from industry and government for advice and assistance in the field of wind energy AWTS presented a proposal to EMR requesting assistance to provide and deliver information and to make available to industry the services and resources of AWTS in an efficient and uncomplicated fashion. The project was approved and terms and conditions and a definition of qualifying work established in a contract between EMR and AWTS.

Since implementation of the program in mid-1986 the Center of Expertise Program has provided assistance to many in the wind energy community. Since its beginning in 1986 the Center of Expertise Program has been renewed and revised on two occasions. During the course of its delivery the program has shown to be an effective and appropriate means for assisting the wind energy industry and community in Canada.

CENTER OF EXPERTISE OBJECTIVES

The overall objective of the program was to operate AWTS as a Center of Expertise to test, monitor, and evaluate WECS, and to provide consulting services for governments, utilities, and small manufacturers conducting research, development, and demonstration of WECS and associated equipment.

The specific objectives of the Center of Expertise were:

1. To maintain facilities, resources, equipment, and personnel capabilities to test and evaluate electrical WECS for: utility scale, grid-connected application; fuel saving in remote communities supplied by diesel generators; and stand-alone systems requiring energy storage.
2. To maintain a comprehensive facility and capability to carry out research and development in wind-diesel technology in companionship with industry and utilities.
3. To develop and conduct research and development projects for government, industry, and users that lead to advances in Canadian wind energy technology.
4. To assist government(s) in the development of programs and projects designed to encourage the achievement of goals for reliable, safe, and economical WECS equipment.
5. To develop techniques for evaluating power and operational performance, reliability, economic performance, and safety factors of WECS.
6. To manage, advise, and provide equipment and personnel to evaluate and monitor WECS demonstration projects at AWTS and throughout Canada.
7. To provide technical advice and information to government(s), industry, and other wind energy community in regard to design, safety, performance, reliability, applications, economics, and other topics related to WECS technology and to provide advice and assistance towards the development of Canadian WECS' standards.

8. To establish and maintain technical liaison with international organizations conducting similar activities and to maintain awareness of standards and techniques for testing of performance, safety, and reliability.
9. To establish and maintain a center of information that is able to:
   (1) provide, locate, and identify sources of technical information, reports, proceedings, experience, and advice to the wind energy community;
   (2) provide current information with regard to ratings, performance, reliability, operating expenses, and cost of Canadian and internationally available WECS; and
   (3) provide information to government, private, and general interest groups.
10. To provide consulting service and advice to Energy, Mines and Resources and to coordinate or direct specific projects or programs at the direction of EMR.
11. To establish a working relationship between EMR and AWTS whereby these actions may be delivered and reported to EMR and the wind energy community in a coordinated and efficient fashion.

SUMMARY OF ACTIVITIES

1986

During its first year of operation the Atlantic Wind Test Site participated in several activities and projects to assist the wind energy community. Principal activities during its first year were:

1. Attendance at meetings of the EMR Technical Advisory Committee on Wind Energy;
2. Provision of a technical advisor for the development of a wind-diesel hybrid generation system simulation model;
3. Field inspection and assessment of a Helio-Beauce wind turbine in Isle de la Madeleine;

4. Preliminary design and development of a Remote Community Demonstration Program project for the Northern Canada Power Commission;
5. Development of a testing program to test an MBB 25 kW wind turbine for Thermax Energy Corporation of Vankleek Hill, Ontario who are Canadian agents and licensed to manufacture the machine in Canada; and
6. Development of plans and arrangements for testing of a Helio-Beauce 25 kW wind turbine. Helio-Beauce is a small Canadian manufacturer involved in the development of small wind turbines for domestic use.

Following completion of its first year of activity a proposal for renewal of the program was submitted to EMR and approved. The second contract was let and with successive amendments and extensions has enabled the Center of Expertise Program to be delivered until March 1990.

1987

In its second year the Center of Expertise Program provided assistance and resources to its previous clients and to several new individuals and organizations. The following are some of the major initiatives undertaken:

1. AWTS personnel assisted EMR in the development of program proposals for an Energy Efficiency and Diversity (EED) Program being developed to deliver renewable energy research and development programs in Canada. The Atlantic Wind Test Site participated in both wind energy sub-committees and in the EED Steering Committee activities.
2. Testing and evaluation of the wind-diesel simulation model being developed by Buchan, Lawton, Parent Ltd. and J. Keller Associates. AWTS engineers provided technical assistance and guidance in the development and testing of the model.

3. Testing of the Helio-Beauce machine continued and assistance was provided to the manufacturer in developing revisions for improved performance of this machine.
4. AWTS continued to provide assistance to MBB engineers in testing and evaluation of the MBB machine.
5. AWTS presented a paper on wind energy systems integration with the electric distribution system at a Canadian Electrical Association (CEA) Conference in Vancouver.
6. AWTS made a presentation on Canadian wind-diesel activities at the British Wind Energy Association (BWEA) Wind/Diesel Workshop at Rutherford Appleton Laboratories in Chilton, England.
7. AWTS provided consulting assistance to the Northern Canada Power Commission to establish terms of reference for a wind farm demonstration project at Cambridge Bay in the Northwest Territories.
8. An AWTS engineer visited the Helio-Beauce factory to inspect equipment and facilities to make recommendations for improvements to design and fabrication of the machine.
9. AWTS engineers were appointed Canadian representatives to the International Energy Agency Annex VIII Decentralized Power Systems Group to assist in the development of a handbook for wind-diesel technology application.
10. AWTS was requested to participate in the IEA Experts Group workshop on Economics of Renewable Energy Technologies and to liaise with technology experts internationally to develop an understanding and techniques for analyzing the economics of wind energy systems.

<u>1988-1989</u>

During 1988-1989 activities of the Center of Expertise centered around continuation of the MBB and Helio-Beauce testing projects at the Atlantic Wind Test Site and provision of technical expertise to EMR through participation in Technical Advisory

Committee meetings, participation in International Energy Agency Annex VIII and in International Electrotechnical Commission standards development. Principal activities during this period were:

1. Attendance at International Electrotechnical Commission Steering Committee meeting in Dubrovnik, Yugoslavia to establish terms of reference for the development of safety, design and operational standards for wind turbine generators.
2. Preparation of chapters on installation, commissioning, maintenance and electrical safety for the IEA Wind-Diesel Guidebook, Siting Technology and Implementation; and
3. Attendance at an IEA Annex VIII Decentralized Wind Energy Systems workshop and meeting in Trondheim, Norway, August 1989.

REPORTS OF ACTIVITIES

During the Center of Expertise Program reports of results of activities have been prepared and provided to clients and EMR confirming the results obtained and work performed. A copy of the principal reports is attached in Appendix A.

CONCLUSION

The Center of Expertise Program has been found to be an efficient and appropriate manner for the delivery of programs to assist and encourage the wind energy community in Canada. The program is very effective in assisting both government and private organizations to further their interests in developing and applying wind energy technology in Canada. The opportunity for those wishing a quick response to requests for information and assistance can be very instrumental in accelerating the development and success of wind energy technology. The Atlantic Wind Test Site's ability to deliver its resources and expertise can most effectively be realized in this fashion. The program has also offered great

flexibility to the EMR Research and Development Program to direct and provide the resources of the Atlantic Wind Test Site most effectively to those wishing this assistance.

RECOMMENDATIONS

The Center of Expertise Program has enabled EMR to efficiently and effectively deliver assistance and information to the wind energy community in Canada. The program has also enabled the Atlantic Wind Test Site to meet its objectives to assist and encourage the industry in Canada and to remain active at a high level of participation in the development of wind energy technology on an international level. It is recommended that this Program continue to be a cornerstone in the future delivery of research and development programs and assistance in Canada.

APPENDIX A

Appendix A

FIRST ANNUAL REPORT

FOR THE

CENTER OF EXPERTISE FOR WIND ENERGY RESEARCH AND DEVELOPMENT IN CANADA

To

Energy, Mines and Resources Canada
Solar Energy Development Program
Wind Energy Division

Contract 23216-6-6012/01-SZ
DSS File 54SZ.23216-6-6012

June 30, 1987

INSTITUTE OF MAN AND RESOURCES
ATLANTIC WIND TEST SITE

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PREFACE

This report presents the results of the first year of a program to provide a Center of Expertise in wind energy at the Atlantic Wind Test Site.

The report summarizes the background, objectives and activities of the program and recommends that the benefit of the program to the wind energy community in Canada be continued.

ABSTRACT

The Atlantic Wind Test Site at North Cape, Prince Edward Island has been established as a Center of Expertise to assist and encourage the design, development and application of safe, reliable and economic wind energy conversion systems. The Center of Expertise is funded by the Solar Energy Development Program of Energy, Mines and Resources Canada. The resources of the Center of Expertise are available to industry, government, utilities and individuals by request to the Atlantic Wind Test Site and/or EMR's Solar Energy Development Program. In its first year of operation the program provided assistance and advice to private and government groups.

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FIRST ANNUAL REPORT FOR THE CENTER OF EXPERTISE FOR WIND ENERGY RESEARCH AND DEVELOPMENT IN CANADA

INTRODUCTION

Wind energy research and development in Canada was commenced by the National Research Council (NRC) in association and cooperation with several other agencies and organizations. Some of these other participants were the provincial power corporations, Indal Technologies Inc. (formerly DAF Indal), IREQ, Lavilan (formerly Shawinigan Engineering), Canada Air, Bristol Aerospace, Adecon Energy Systems, the Institute of Man and Resources (IMR) and others. Most of the participants were involved in specific projects oriented around specific hardware and technology. IMR however, through development of the Atlantic Wind Test Site (AWTS) and involvement in many varied research and development projects emerged as a more broadly based organization with resources and expertise in many areas. The National Research Council's Energy Division recognizing this circumstance selected AWTS as a national Center of Expertise in 1981 and established a ten year contribution and operating agreement with the AWTS to enable AWTS to operate and to participate actively in Canadian wind energy technology development. The AWTS role being to provide testing and evaluation services and serve as a national resource for assistance to industry, users and other interested organizations. The AWTS also participated actively in standards development, advisory groups in Canada and in international technical conferences and workshops.

In 1984 following announcement of the planned dismantling of the NRC Energy Division and transferal of the Canadian R&D mandate to Energy, Mines and Resources (EMR) an industry workshop was convened by EMR at Montebello, P.Q., to provide input and advice to EMR for development of their planned R&D program. One of the elements recommended for inclusion in the program was the establishment and support of Centers of Expertise for wind energy and also for other renewable technologies. The recommendation specifically named the Atlantic Wind Test Site in Prince Edward Island and the Lethbridge Test Centre for water pumping turbine testing in Albedrta as the proposed Centers of Expertise for wind electrical and water pumping technology respectively.

In FY 1986 at commencement of the EMR sponsored R&D program a proposal to EMR for operation of a limited Center of Expertise program was presented to EMR. In April 1986 a $40,000 budget was approved and provided by EMR for performance of specific work to assist Canadian industry and others in the persuit of wind energy technology development.

Specific areas of work considered in this development of the Center of Expertise budget for FY 1986 were:

Testing:
1. performance testing at AWTS
2. field monitoring of demonstration WECS
3. site monitoring

Consulting and services:
1. participation in EMR Technical Advisory Committee
2. technical advice to EMR
3. demonstration project management
4. design assistance to small manufacturers

These work areas were intended for general guidance only, as it was anticipated that demands on the program may not necessarily conform to these preconceived needs.

OBJECTIVES

Specific objectives, activities, and responsibilities of the Center of Expertise were:

1. To maintain facilities, resources, equipment, and personnel capabilities to test and evaluate electrical wind energy conversion systems for utility scale grid-connected application, fuel saving in remote communities supplied by diesel generators, and stand-alone systems requiring energy storage.
2. To establish a comprehensive facility and capability to carry out research and development in wind/diesel technology in companionship with industry and utilities.
3. To develop and conduct research and development projects for government, industry, and users that lead to advances in Canadian wind energy technology.
4. To assist government(s) in the development of programs and projects designed to encourage the achievement of goals for reliable, safe, and economical WECS equipment.

5. To develop techniques for evaluating power and operational performance, reliability, economic performance, and safety factors of electrical wind energy conversion systems (EWECS).
6. To manage, advise and provide equipment and personnel to evaluate and monitor WECS demonstration projects at AWTS and throughout Canada.
7. To provide technical advice and information to government(s), industry, and other wind energy community in regard to design, safety, performance, reliability, applications, economics, and other topics related to WECS technology and to provide advice and assistance towards the development of Canadian WECS' standards.
8. To establish and maintain technical liaison with international organizations conducting similar activities and to maintain awareness of standards and techniques for testing of performance, safety, and reliability.
9. To establish and maintain a centre of information that is able to:
   (a) provide, locate, and identify sources of technical information, reports, proceedings, experience, and advice to the wind energy community;
   (b) provide current information with regard to ratings, performance, reliability, operating expenses, and cost of Canadian and internationally available EWECS.;
   (c) provide information to government, private and general interest groups.
10. To provide consulting service and advice to Energy, Mines and Resources (EMR) and to coordinate or direct specific projects or programs at the direction of EMR.
11. To establish a working relationship between EMR and AWTS whereby these actions may be delivered and reported to EMR and the wind energy community in a coordinated and efficient fashion.

ACTIVITIES

The following is a summarized account of activities and services provided by the Center of Expertise in the first term.

Technical Advisory Committee Meetings

Technical Advisory Committee Meetings were attended and chaired by Malcolm Lodge on May 5, 1986, October 21, 1986 and June 16 1987.

Contractor Meetings

Meetings were held with Buchan, Lawton and Parent Ltd., NRC and EMR to initiate work and review progress on development of a wind/diesel simulation model. Meetings were held on July 29, 1986, October 22, 1986, February 3, 1987 and June 17, 1987.

Other Meetings

Malcolm Lodge attended an IEA wind/diesel subcommittee in Vastervik, Sweden, June 3, 4 and 5, 1987.

Conferences, Workshops

M. Lodge prepared and presented the following papers:

Parallel Generation with Wind Turbines - Technology and Experience, Canadian Electrical Association Conference, Vancouver, B.C., March 31, 1987.

Wind/Diesel Research and Development in Canada, Rutherford Appleton Laboratory Wind/Diesel Workshop, Chilton, England, June 1 & 2 1987.

Consultations

- M. Lodge visited Isles de la Madeleine on November 19 and 20, 1986 to inspect and observe operation of the Heli-O-Beauce wind turbine erected there. A trip report describing findings and recommending further action has been prepared. The report recommends testing on site for the remainder of the year to determine basic operational characteristics and also to do a design review to identify potential design problems and provide input for possible design modification. The unit shows promise particularly as a wind turbine to provide direct space heating.
- M. Lodge visited the Northern Canada Power Commission (NCPC) in Edmonton on December 16 to assist with development of terms of reference for a RCDP wind energy project proposed for Cambridge Bay.

- Carl Brothers visited Heli-O-Beauce Inc. in St. George, P.Q. to inspect equipment and facilities. A report describing his findings and making recommendations for ongoing work has been prepared.

Other Work

Liaison has been initiated and maintained with Thermax and MBB regarding testing and evaluation of a prototype unit when available. Latest plans call for testing at AWTS commencing September 1987.

Project Cost Summary

Costs to date to perform the work described are summarized below.

Labour	$11,698
Direct	
Travel	8,112
Telephone	390
Misc.	192
	$20,392

CONCLUSION

During the first year of its operation the Center of Expertise performed many of the tasks planned. Testing and evaluation projects for Heli-O-Beauce and Thermax/MBB at AWTS did not materialize due to delays in production of the machines by the suppliers.

Expenditures were about half of those planned because of the non-availability of machines for testing.

The ability to provide advice and consulting services to industry and other government groups and to provide testing, monitoring and related work with minimum delay, and to quickly make agreements and arrangements provides for more efficient and responsive delivery of AWTS resources and dispersion of funds set aside for this activity in EMR's Solar Energy Development Program.

RECOMMENDATIONS

Although events and circumstances did not allow the Center of Expertise program to fully realize its planned goals, particularly in the area of testing and evaluation of equipment, the Center of Expertise was

effective in making provision of information, technical and expertise and other resources of the AWTS which otherwise would not have been so fully and quickly available.

The AWTS recommends that the program be continued and that no change in operation is necessary to effectively deliver the program.

A proposal for continuing work for 1987 has been presented to EMR's Solar Energy Development Program.

APPENDIX B

Appendix B

HELIO-BEAUCE PERFORMANCE AND OPERATIONAL EVALUATION
Atlantic Wind Test Site June 30, 1987

Helio-Beauce is a small wind turbine manufacturer in St. Georges in Beauce, Quebec. The company produces two small wind turbines rated nominally at 8 and 25 kW. They are designed primarily for small installations such as farms or residential space heating applications.

As with many small companies this firm lacked sufficient technical expertise to fully analyze and resolve many design issues. AWTS was asked to assist the company in improving it's product by carrying out a performance and reliability test on the larger of the two units known as the Boreal unit rated nominally at 25 kW.

MACHINE DESCRIPTION

The Boreal machine is a downwind, 3 bladed horizontal axis wind turbine with passively controlled pitch regulation of the blades. The blades are made of fibreglass with urethane foam injected between the two fibreglass halves. The blades are connected to the hub by steel struts. These struts are comprised of two flat steel bars that are bent and connected to the blades in such a manner that both centrifugal and flatwise loading on the blades tends to straighten the bars and causes the blade to pitch slightly into stall. This provides passively controlled overspeed protection.

The rotor is connected to a main shaft which is carried by two pillow block bearings. A large hub on the in-board end of the shaft provides a drum brake on the inside and a low speed sheave on the outside for a "poly-v-belt" speed increaser. The brake is a spring actuated device in which a pin is inserted to hold the brake disengaged. The brake is automatically engaged by machine vibration or manually from a line hanging from the nacelle. The V-belt drives a 20 kW single phase alternator which provides the electrical energy. The generator is a Leroy-Somer A1610M7 single phase alternator with a Leroy-Somer Type R5128A regulator. All the sheaves, shafting and other mechanical apparatus are manufactured in Helio-Beauce's shop.

The entire rotating assembly is mounted to the yaw shaft by a large flat spring steel bar, which provides resiliency. The yaw shaft turns on the tower top adapter with two bearings and open slip rings to transmit the power across the rotating interface.

A typical tower installation is comprised of a 50 foot utility pole having a minimum diameter of 9" inserted in the ground about 5 feet. Guys are attached to the pole at points 3 and 10 feet from

the pole top. The eight guys are then attached to four anchors located about 30 feet from the base. These consist of a 5-10 foot length of 12 inch diameter utility pole buried to a depth of 5 feet.

INSTALLATION AND OPERATION

The machine was installed in the fall of 1987 on an existing AWTS test pad and operated through the fall and early winter in an autonomous variable speed mode with the energy produced used for space heating. Several problems were experienced during this period and the machine was eventually taken out of service in early 1988 after a blade strut failure caused severe vibration. A report was submitted to Helio-Beauce at that time with recommended areas for improvement. A modified unit was supplied from Helio-Beauce in the summer of 1988 having some of the recommended modifications carried out. Efforts to install the machine in a grid connected configuration using line commutated inverters were abandoned after several days due to problems with the inverters. The machine was then tested in a space heating mode for several weeks before further problems with the rotor forced the unit out of service permanently. Helio-Beauce was informed of the problem and plans were made to repair the machine. No action was taken however due to financial limitation with the manufacturer. The machine remains inoperative at AWTS and will be removed from the test pad when site conditions permit.

SIGNIFICANT EVENTS LOG

June 1987	C.Brothers visited Helio-Beauce to evaluate the possibility of collaborative work between AWTS and Helio-Beauce. A number of potential problem areas were identified for design improvements.
Oct 28/87	Helio-Beauce installed a machine on a fabricated steel tower. The machine ran fairly well over a range of wind speeds. Power output was lower than expected. The resistive load supplied was not adequate for continuous operation.
Nov 13/87	The drive belt, was destroyed as a result of, failing the brake.
Nov 23/87	Helio-Beauce returned to site to replace belt, make repairs and restart machine. The brake was not operational. Electrical load was scheduled for replacement by December/87. The machine was operating but without a brake when F.Trepanier of Helio-Beauce left site.
Dec 2/87	Preliminary test results show rotor efficiency at less than 25%.

Dec 10-20/87	Problems with dump loads persisted. The improved load has not been received.
Jan 7/87	We arrived on site to find the machine running wildly and lowered it under very unpleasant circumstances. The blades were seriously damaged by mechanical failure of the rotor pitch mechanism.
April 25/88	The machine was out of service since January. C.Brothers visited Helio-Beauce to investigate status of proposed improvements. Some substantial improvements to brake and pitch control system had been made but other problems remain. We agreed to have second machine erected at AWTS for further testing and development.
July 24/88	New Helio-Beauce machine arrives. Complete with a wooden pole tower. The machine was to be grid connected using line commutated inverters. After numerous problems with inverters they were discarded. F.Trepanier left site to redesign system with induction generator.
Nov 1988	F.Trepanier returned to site but without an induction generator. He installed new space heaters as a load. Machine develops vibration problems which are diminished by addition of mass damper arrangement on rotor. F.Trepanier leaves site on November 27 satisfied with machines performance.
Dec 5/88	Helio-Beauce stopped. Three blade struts have broken and machine inoperable.

APPENDIX C

Wind Energy Converter MONOPTEROS 20

The MONOPTEROS 20, rated at 20 kW is the smallest of the three WEC-Systems manufactured by MBB. Three prototypes have been in operation since 1981. One machine has been operated more than 700 hours up to now connected to the grid and the performance has been proven. More than 20 kW are achieved at 14 m/s wind and the unit is automatically starting at about 3,5 m/s beeing connected to the grid down to 4,0 m/s.

The system is applicable to feed power into an existing grid (asynchronous generator) as well as to supply remote stations with energy for lighting, cooling, water irrigation or water desalination (synchronuous generator with power management for rotor speed stabilisation). Even the supply of the biological sewage plant in combination with a diesel engine has been projected. Fig. 1 shows this application and fig. 2 describes a water irrigation system.

Design philosophy

MONOPTEROS 20 has been developed as a low cost WEC for power outputs between 10 and 30 kW depending on site and application. Low maintenance cost and high reliablility are the major design goals. To avoid complex and expensive rotor controls the "stall controlled" rotor concept has been chosen. The single rotorblade which is mounted in a hinge and balanced by a counterweight is kept in a fix pitch position during power production at all wind speeds. The aerodynamic stall increasing from the rotor blade root with increasing wind speed limits the power output to a maximum of about 32 kW at 15 m/s wind speed.

The rotor is running downstream of the tower and is free in yaw stabilized by vertical mounted fins (weather cock stability).

All the loads from the rotor aerodynamics, mainly the aerodynamically unballanced tangential force (driving force) and gust loads are absorbed by the system without great structural forces because the flexible design using:

- cardanic rotor hub
- free motion of the power train in the vertical plane
- free yaw motion

Because of the rotor hinge the blade bending moments at normal running and high gust conditions are kept to a minimum.

This principle and running the single blade at supercritical speed regarding the tower first bending eigenfrequency have lead to an extreme light weight concept. The consequent use of proven materials and standard components from serial products have made the MONOPTEROS 20 beeing a verry competitive WEC.
A general view of the system is presented in fig. 3.

Performance

Rotor efficiency maximum is 38% at about 8 m/s wind speed. Cut in wind speed is 3,5 m/s and rated power (standard 20 kW) is reached at 10,5 m/s. The power characteristic is shown in fig. 4 and fig. 5 allows to calculate the annual energy for various sites as a function of mean annual wind speed. As an example, the daily variation of electric power by the MONOPTEROS 20 is plotted for three seasons for the site Kandla, according to Indian sources of wind speed data (fig. 6).

DESIGN

Tower

The 15 m high steel tower is of tubular design and is stabilizied by 4cables. The cables are mounted on a bearing ring so that the entire tower with the machinery and rotor can rotate free in yaw. This concept allows the electric and hydraulic connection of the power supply and control system mounted at the bottom of the tower with the system of the generator and rotor on top without any sliprings.

The tower is standing on a ball bearing and can be lowered by a simple auxiliary beam and a hoist into horizontal position. This simplifies maintenance and repair. The tower can quickly be lowered if extreme gale winds are predicted. The five foundation poles are made from concrete, the mounting of tower, hoist and cables on the foundation is facilitated by simple cast-in bolts and reinforcement steel.

Power generation package

Rotorhub, mainshaft, cardanic transmission shaft, gear box, generator and hydraulic disc brake are mounted in line, in a tubular structure. This tubular power train is mounted on the tower top in a bearing which allows free vertical motion of the part when the system is exited by aerodynamic loads from the rotor. This motion is controlled by a mechanically damped spring keeping the power train in horizontal position.

The rotor shaft is running in two ball/roller bearings sized for long life. The torque is transmitted by a cardanic shaft to the gearbox. The gearbox (ratio 1:15) shall be either of the planetary type or the so called "Cyclo gear" which is currently installed on the prototyp with good experience. Between gearbox and generator a well dimensioned disc brake is mounted. This brake can absorb more than twice of the brake energy of the rotor at design speed and can be operated either by hand using a simple pump mounted at the root of the tower or automatically by the control system.

Rotor

The rotor consists of one 6 m long blade mounted to a steel hub which is integral part with the structure holding the counter balance weight. The rotor is mounted to the shaft by means of a standard cardanic hinge.

This cardanic hinge allows the rotor to be pitched in a range of about 45° to enable starting/parking of the machine as well as to flap in an angle range of +10° to -15°. The flapping is limited by rubber stops.

At failure condtions like

- hydraulic fault
- electrical supply fault for the control system
- asymmetry in the generator el. system
- frequency deviation greater 5%

the rotor blade will be turned back to -45° and the generator disconnected from the grid.

In case of abnormal vibration of the rotor the system is brought to stop immediately by the hydraulic disc brake.

The hydraulic actuator for blade pitch is acting against a spring. This spring pushes back the actuator whenever a failure in the hydraulics or electrics occurs and is a "fail safe" device to prohibit the unit to overspeed.

On top of the normal control there are two speed limits:

- at 125% speed by an electronic speed detector
- at 135% speed by an mechanical overspeed switch.

Both signals open the return line for the hydraulic piston and the spring brings the system back into a safe mode, i. e. pitch angle -45°.

Electrical equipment

MONOPTEROS 20 is available with two electrical systems:

a) The standard generator system shall be a 20 kW induction generator with 380 V voltage feeding directly the consumer without any transformer. However the adaptation to other voltage ranges (e. g. 400 V) is possible. Various generator supplies may be used if matching with the mechanical mounting interface (flange and shaft coupling) is feasable.

At low wind sites for economy reasons a smaller sized generator max be used. A site having 5,5 m/s mean annual wind speed may be better suited with a 15 kW generator.

b) For isolated island operation a synchronous generator of 20 kW shall be used. In this application the system rotational speed is controlled by a simple power management system which feeds excess power to dummy loads. The rotor speed is kept inside ± 2% deviation from rated speed.

In the island operation the unit shall be equipped with a battery to supply power to the control system when the unit is not producing power.

For hybrid power production (e. g. photo-voltaic or diesel and wind) it is proposed to supply the power to a joint DC-bus via AC/DC converter.

Pitch motion of the blade is facilitated by a hydraulic actuator which rotates with the rotor hub and is supplied with hydraulic power via a hydraulic slipring mounted on the main shaft.

Blade

The blade aerodynamic profile has been developed by the Institute of Aerodynamics and Gasdynamics of the University of Stuttgart (Prof. Wortmann) and has the designation FX-84-W-127. This section has a very good L/D ratio and a soft stalling and post stall characteristic. The blade has a simple rectangular plan form (constant cord length of 0,5 m) and no twist.

The structure of the blade is from GRP with supporting foam core. Attachement of the blade to the hub is by shear bolts using well established technique from helicopter developments.

Control system

Beeing not connected to the grid the rotor is allways running with a blade pitch angle -45° (Parking) or -30° (Starting position) and is acting like an anemometer. So the rotor speed is taken as a measure for wind speed. Fig. 7 describes the control function.

At wind speeds below 4,5 m/s the rotor is in starting position with the blade pitch set to -30°. If rotor speed increases above 16% a start is automatically initiated and the blade pitch angle is set with well controlled speed to 0° (power production mode). The rotor accellerates and passing 100% (synchronization speed) the control system connects the generator to the grid.

Disconnection from the grid shall be at the following conditions:

- negative power
- more than 22 kW power (depending on generator size) at too high wind speed. If wind speed drops reconnection to the grid shall be automatically

Technical Data

Rotor

No. of blades	: 1
Diameter	: 12,5 m
RPM	: 100/min
Rotorposition	: downwind
Hubtyp	: teetered
Blade pitch pos.	: 0° Operating mode
	45° Windmill oper. mode
	30° starting mode

Rotorblade

Length	: 6 m
Blade cord	: 0,5 m at v/R = 0,05; 0,25 m at v/R = 1
Profile	: FX 84 W 127

Tower

Material	: turbular steel
Stabilization	: 4 steel cables
Corrosion Protection	: zinc plated
Height	: 15 m

Generatorsystem

Generator typ	: asynchronous/synchronous
Power output	: 15 - 30 KW
RPM	: 1500/min
Gear Ratio	: 1 : 15
Cut-in windspeed	: 4,5 m/s
Cut-out windspeed	: 18 m/sec
Max design windsp.	: 60 m/s

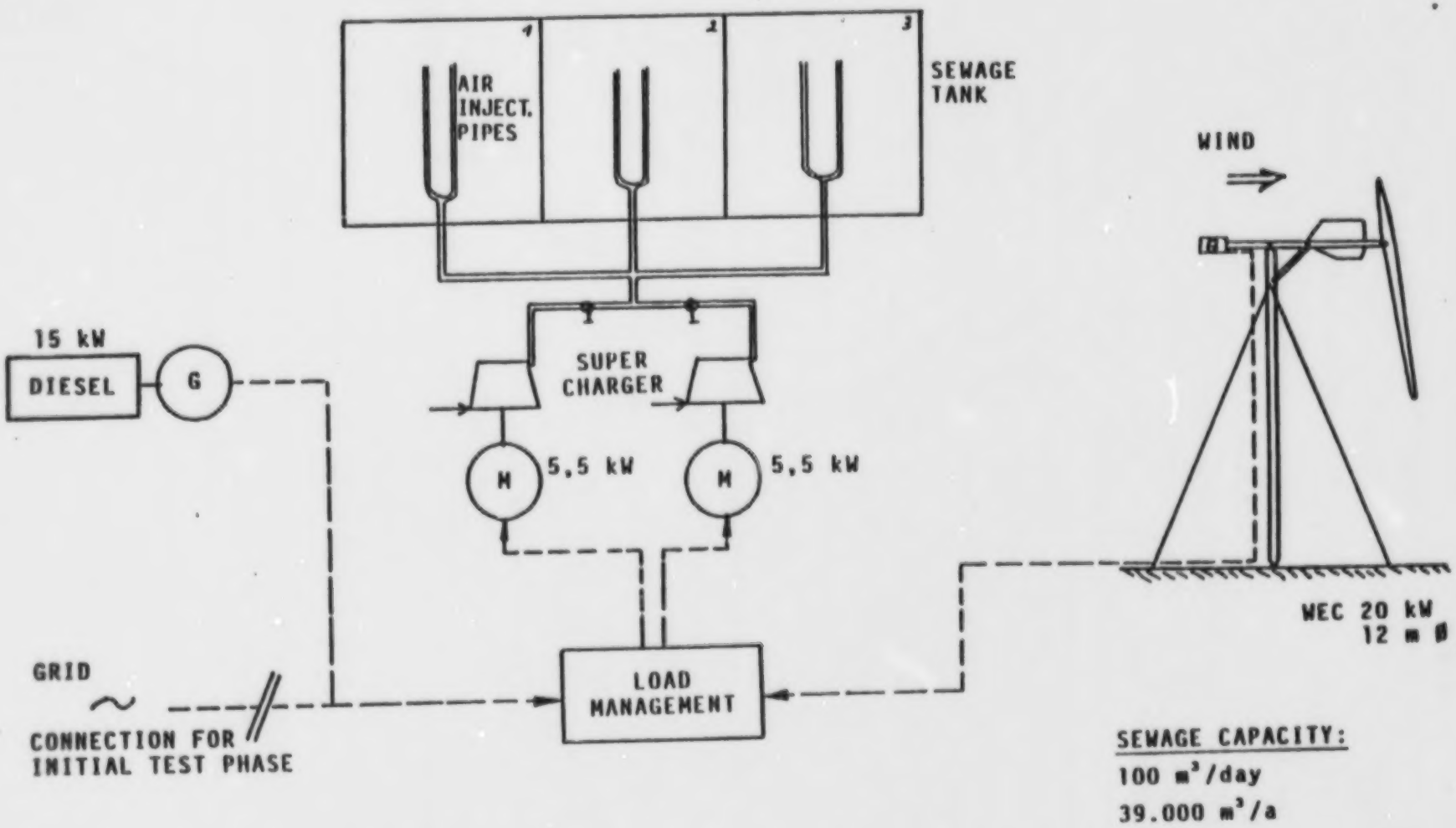
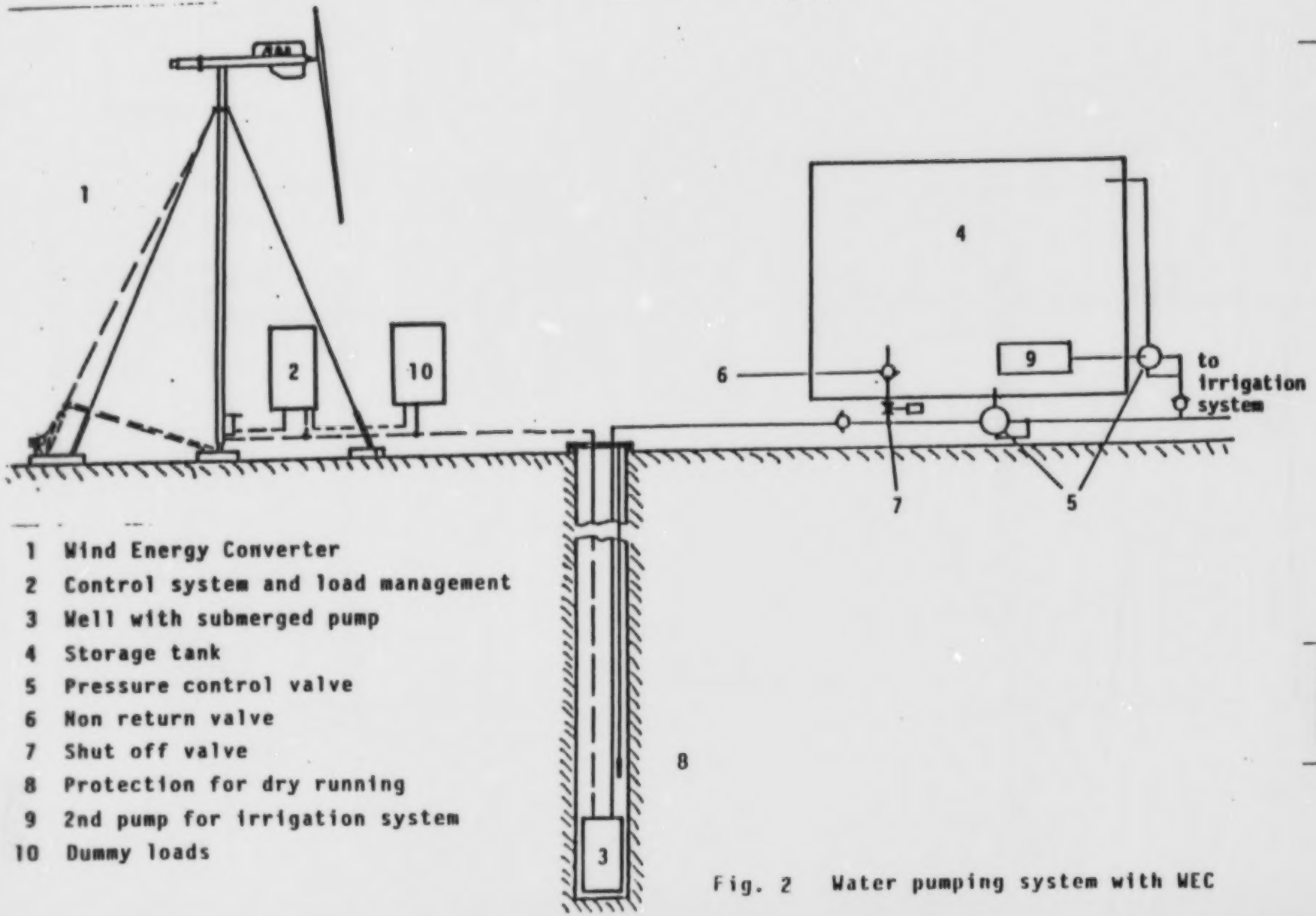


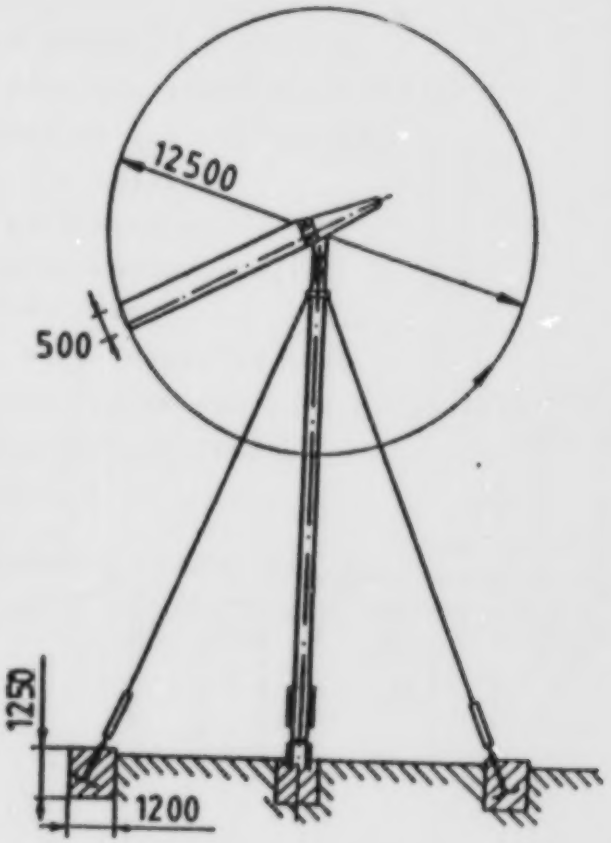
Fig. 1 SCHEME OF THE COMBINED WEC AND SEWAGE PLANT



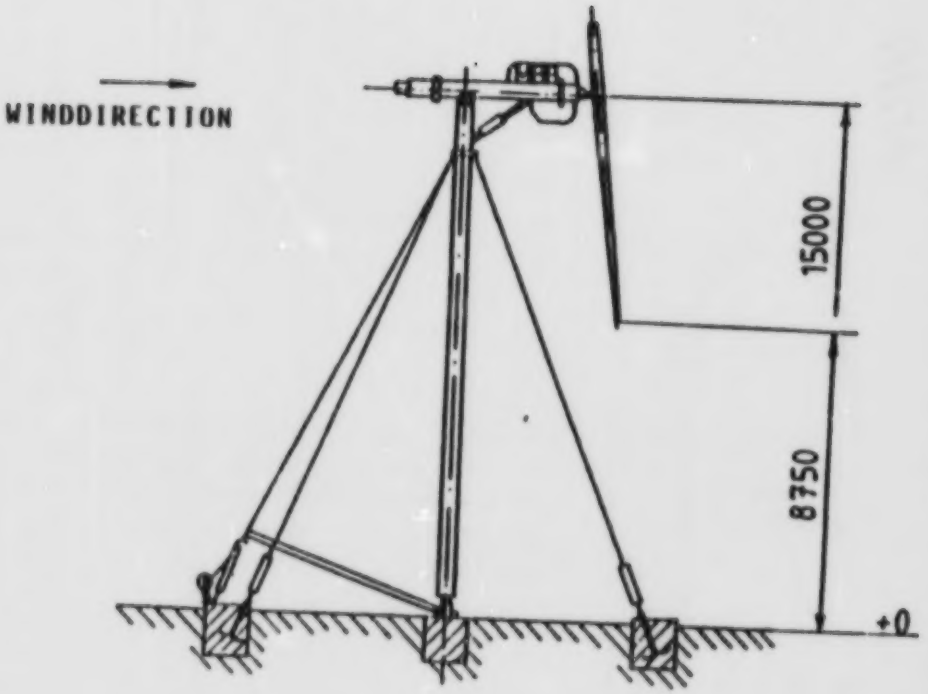
1 Wind Energy Converter
2 Control system and load management
3 Well with submerged pump
4 Storage tank
5 Pressure control valve
6 Non return valve
7 Shut off valve
8 Protection for dry running
9 2nd pump for irrigation system
10 Dummy loads

Fig. 2 Water pumping system with WEC

MBB

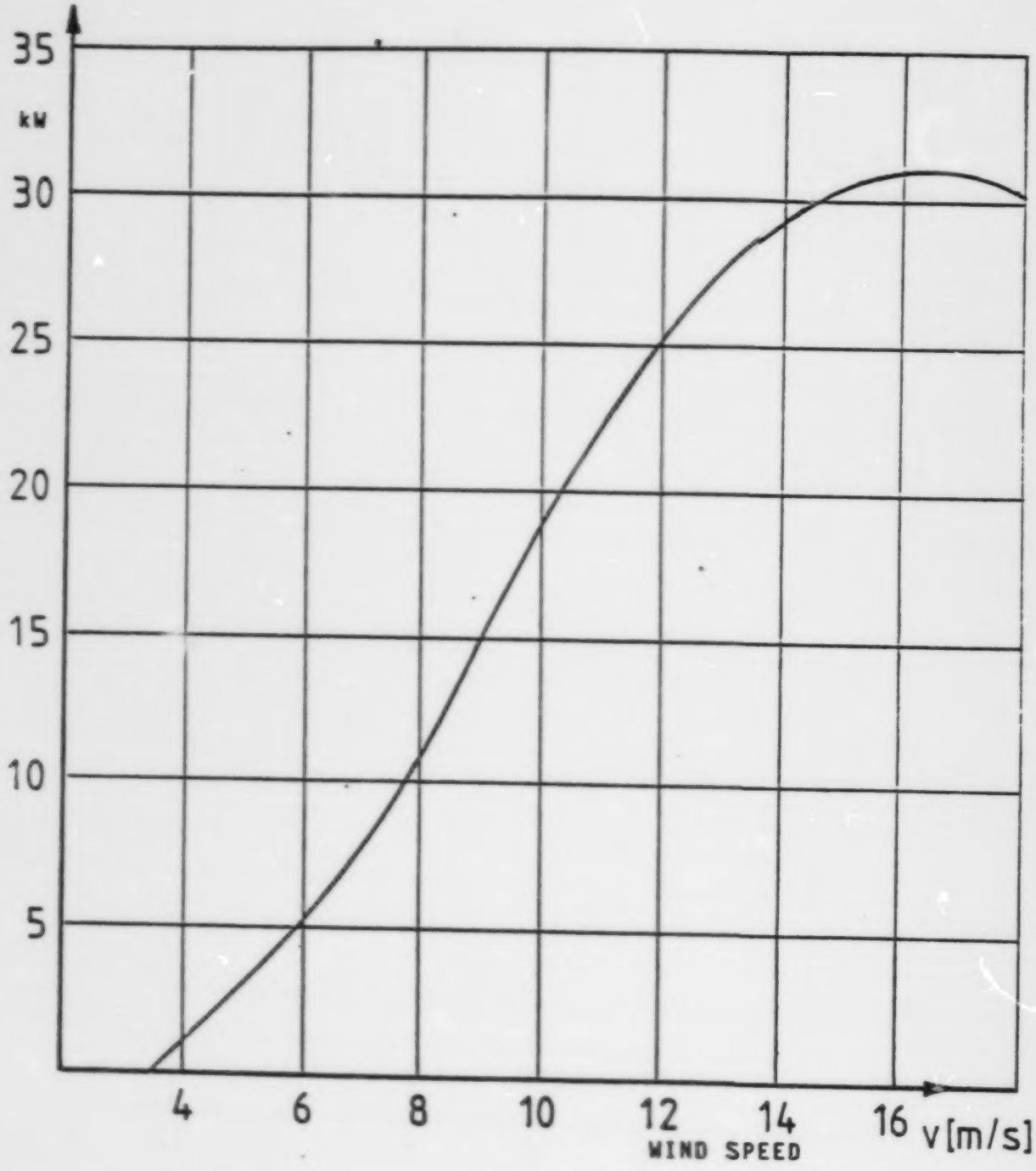


FOUNDATION



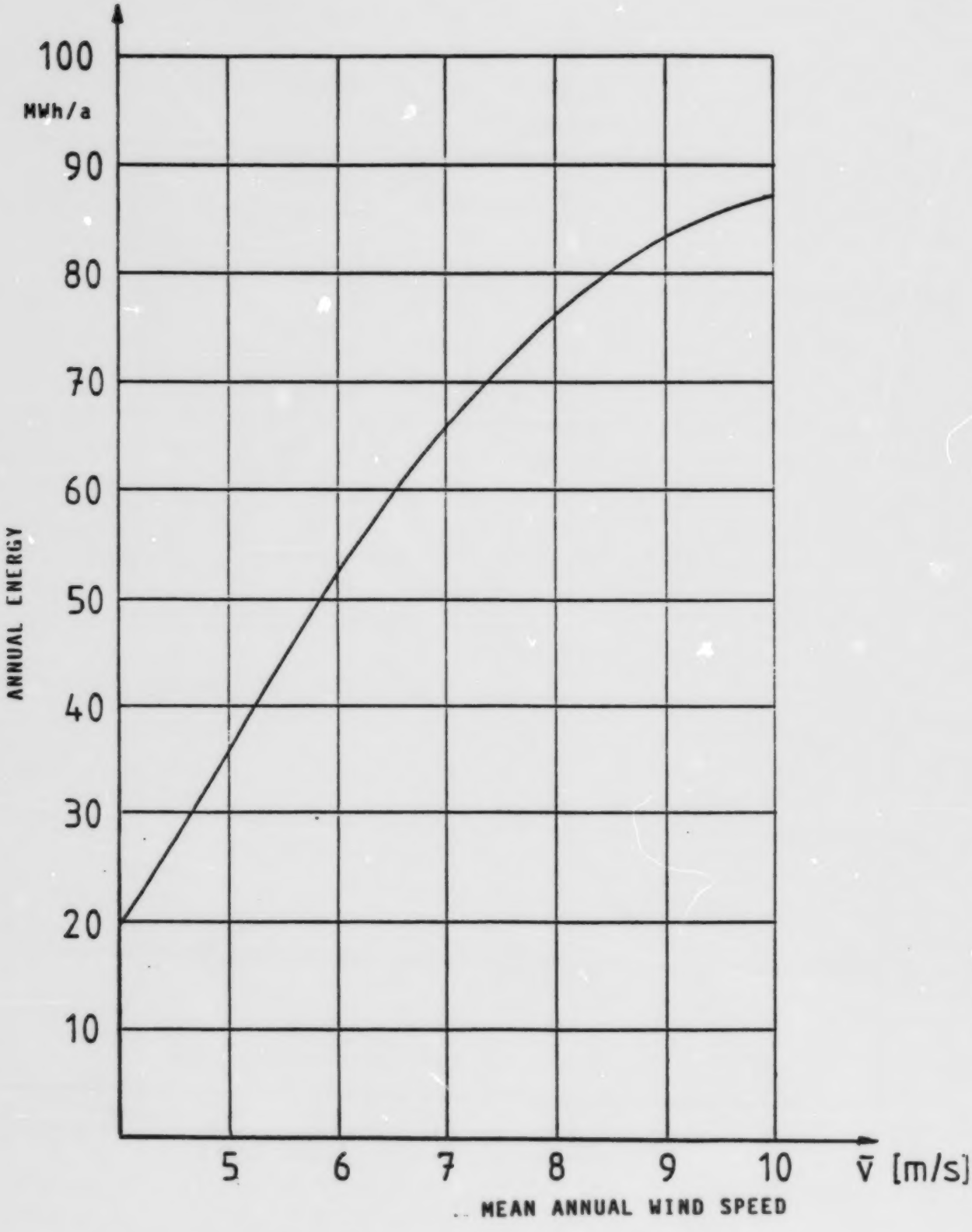
MAIN DIMENSIONS OF MONOPIEROS 20

MBB



PERFORMANCE OF MONOPTEROS 20

MBB



ANNUAL ENERGY PRODUCTION OF MONOPTEROS 20

MBB

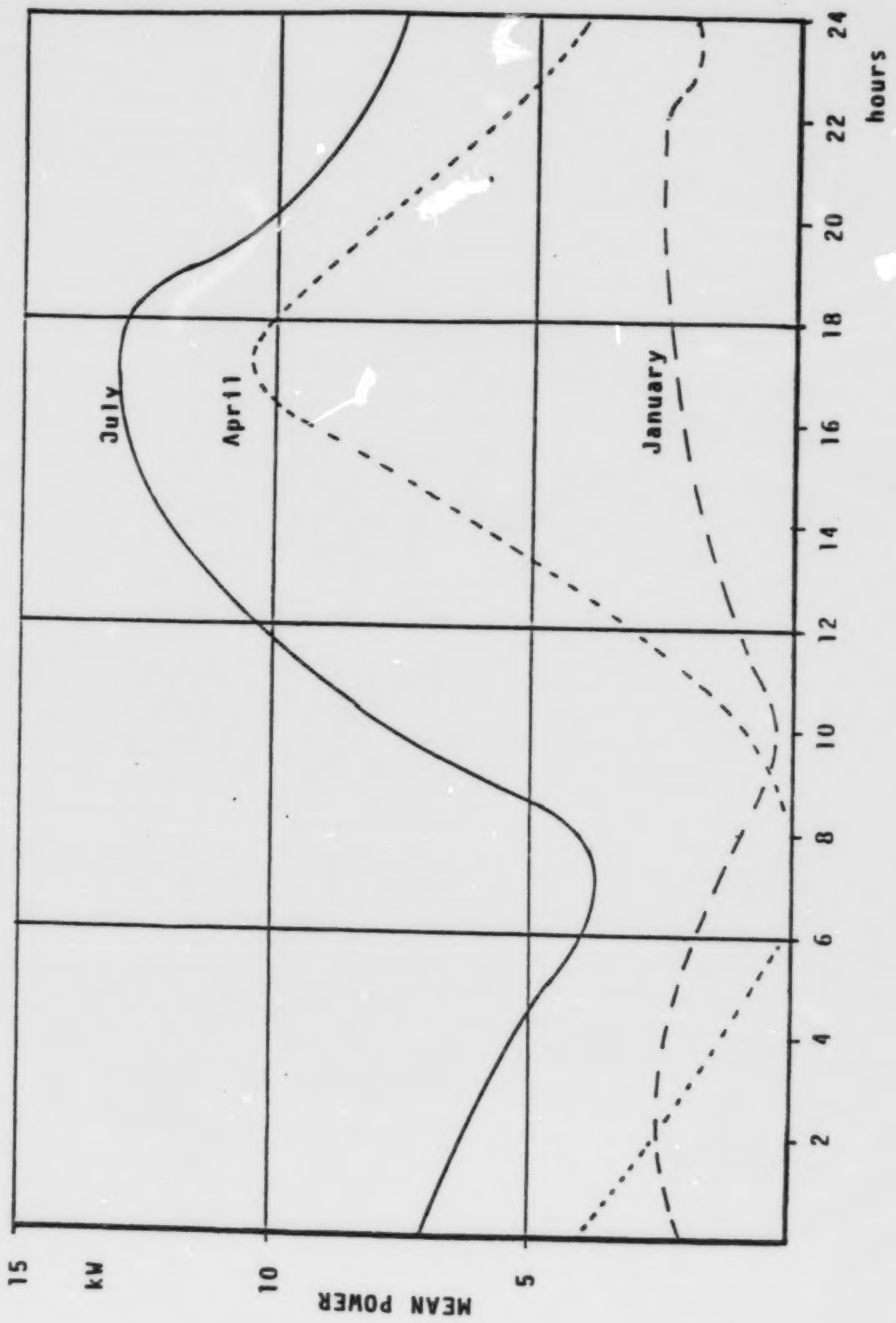


Fig. 6 Diurnal mean power by Monopteros 20 in Kandla

APPENDIX D

Appendix D

MBB MON 15 PERFORMANCE AND OPERATIONAL EVALUATION
Atlantic Wind Test Site June 6, 1989

MBB is a large German aerospace company that has been developing wind turbines in a range of sizes over the last decade. The distribution rights for North America were obtained by Thermax, a Canadian distributor which markets a range of small wind turbine products. The first MBB product that Thermax planned to introduce to the North American market was the Mon 15, a single bladed machine rated at 30 kW.

To obtain performance and operational experience with the machine in a North American configuration, Thermax requested a test program for the machine at the Atlantic Wind Test Site under the Center of Expertise program.

MACHINE DESCRIPTION

The machine is a single bladed unit with a 7.5 meter fibreglass blade which is balanced by a steel counter weight on the opposite end of the rotor. The rotor is connected by a flexible shaft, to a helical gear box and 30 kW induction generator. Power output is controlled by a computer controlled hydraulic cylinder which varies the pitch of the blade. The machine is mounted on a 20 meter tower that operates in free yaw with the rotor downwind of the tower.

MACHINE INSTALLATION AND OPERATION

AWTS staff installed special foundations necessary and modified and adjusted the site grid connection and data acquisition systems to enable testing to be carried out.

As the attached summary log indicates the machine was delivered and erected at AWTS in the spring of 1988. Tests carried out on the machine over a six month period revealed many problems typical of a prototype that would not be acceptable on a commercial model. Two trips were made from Germany to AWTS by MBB engineers to resolve the many operational problems. Both trips were unsuccessful in achieving reliable operation. MBB ultimately decided to take the machine back for some substantial design modifications prior to further testing at AWTS.

Concurrent to the decision to terminate testing, an internal reorganization at MBB resulted in cancelation of plans to continue development of their machine.

SIGNIFICANT EVENTS LOG

Feb 17, 1988	MBB MON 15 arrived at AWTS in container. Gosse de Haan from MBB Helicopter Canada on site to supervise assembly and erection.
Feb 21, 1988	Machine erected but EPROM not available to operate machine. Gosse de Haan returns to MBB.
Feb 24, 1988	Machine lowered due to problems with impact of blade on teeter stop.
Mar 23, 1988	Gosse de Haan and two German engineers arrive with EPROM to commission machine.
Mar 30, 1988	MBB personnel leave site. EPROM still problematic. Machine not operating.
Apr 6, 1988	Replacement EPROM received. Problems persist with power supply board.
Apr 8, 1988	Machine repaired and operational however intermittent problem causes blowing of fuses in thyristors circuits.
Apr 12, 1988	Machine operating intermittently in low to moderate winds. Needs frequent attention to reset trips and faults.
Apr 18, 1988	Intermittent problems persist with control system and fuses on circuit board. Continued operation in low to medium winds.
Apr 29, 1988	Machine shut down. Both speed sensors are shorted due to rainwater ingress to control box.
May 9, 1988	Machine repaired and raised but operates intermittently. Noted broken strands on lift cable. Replaced cable.
May 10, 1988	Machine blew final two fuses on thyristors. Having no spares the unit was shut down.
Aug 8, 1988	Parts for modifications to pitch control cylinder arrived. Gosse de Haan arrives to make system operational.
Aug 10, 1988	Machine raised and tested. Fuses blew after a few hours.
Aug 26, 1988	Gosse de Haan returned to MBB. Machine remained inoperative.

Sept 15, 1988	**Gosse de Haan and two German engineers arrive at AWTS.**
Oct 4, 1988	MBB personnel depart AWTS after many modifications to machine; - generator was rewound upon discovering a snorted winding. - new blade and counter weight were installed. - hydraulic system replumbed. - control system modified. Machine operational in low to moderate winds. Need new EPROM for high wind operation.
Nov 4, 1988	Machine will not run. Problems related to cold temperature, overspeed monitoring circuit and proportional valve.
Nov 10, 1988	Machine shut down due to overheated hydraulic pump.
January 1989	Replaced EPROM and tried restarting machine. Machine repeatedly overspeeds and cannot be operated.
Feb 17, 1989	P. Krauss called from MBB. He informed that MBB plan to remove machine.
Mar 16, 1989	Received request from MBB to disassemble machine and store at AWTS until a replacement machine can be delivered in August/September, 1989. No discussion of a further test program has been held.

APPENDIX E

Appendix E

CANADIAN ELECTRICAL ASSOCIATION

Distribution System Planning and Operating Subsection

Distribution Section

Engineering and Operating Division

March 1987

Vancouver

PARALLEL GENERATION WITH WIND TURBINES - TECHNOLOGY AND EXPERIENCE

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SUMMARY

Almost twenty thousand wind energy conversion systems are connected to major electric utility grids around the world. Installations range from single small machines to arrays of hundreds of interconnected machines called wind farms. Techniques that stress safety in design have been developed and proven that represent no safety, performance or financial threat or risk to utility generation and distribution systems. Standard guidelines for virtually all aspects of WECS utility applications have been developed by CSA and similar bodies in other countries. Many utilities have established interconnection policies and regulations. Uniform requirements ratified by Canadian industry and utilities would be desirable.

Keywords: Wind energy, parallel connection, and wind energy standards.

PARALLEL GENERATION WITH WIND TURBINES - TECHNOLOGY AND EXPERIENCE

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1. INTRODUCTION

During the last 15 years since the renewal of interest in alternative sources of energy for production of electricity, wind power has been recognized to have great potential for future development. In remote locations where no hydro power is possible and diesel engines or combustion turbine driven generators are used, wind turbines or wind energy conversion systems (WECS) offer an attractive alternative now. In future as costs of coal and oil increase and environmental and safety concerns regarding acid rain and nuclear waste continue, wind energy may become an element of many utility generation expansion plans. The wind farms in California, many of which contain several hundred machines provide evidence that wind can be integrated into utility grids without difficulty and that acceptable reliability and performance can be achieved.

In the beginning when large wind turbines were first considered as sources of energy for utility application, there were many concerns regarding the safety, quality of power and performance of the grid when wind turbines are connected. After ten years of experimentation, demonstration and practical field experience, means and techniques to eliminate virtually all potential problems of interconnection have been devised. Although more complex than the ease that Fig. 1 suggests the technology and equipment necessary for safe and reliable connection is relatively state of the art. A brief description of some of the systems used and their characteristics follow.

2. WIND TURBINE TYPES

Wind turbines for generation of electricity may be of either the horizontal axis (HAWT) or vertical axis (VAWT) types. Horizontal axis machines may have two or three aerodynamically shaped blades that are connected to a generation system that usually consists of a speed increasing gear box that in turn drives an alternator or induction generator. An induction generator is essentially an induction motor which when driven in excess of synchronous speed becomes a generator of power. To regulate power the blades may be varied in pitch or designed to install in high winds thus limiting maximum power output. For reasons of cost and simplicity, most machines use fixed pitch, stall regulated rotors and induction generators. The induction generator does not require expensive syncronizing controls or excitation apparatus and is more reliable. It however usually requires that the grid be supplied from the utility to provide excitation of the induction generator stator. Figures 2 and 3 illustrate typical horizontal axis technology.

Vertical axis machines are usually of the Darrieus type having two or three symetrical aerodynamic blades. For reasons of cost, assembly effort and erection effort the machines usually have only two blades. Like the horizontal axis machines the rotor usually drives an induction generator through a speed increasing gear box. The rotor blades are fixed in pitch and stall at high wind speeds to limit power production. Fig. 4 illustrates a Canadian VAWT system.

Both HAWTs and VAWTs usually run at constant speed unless they are coupled to the grid through solid state inverters, frequency changing equipment, or use wound rotor generators. The choice of generator type has an important bearing on other design aspects of a WECS.

There are many possible permutations and combinations of rotor, drive train, generator and control design possible. The choice is usually made with the objective of achieving minimum costs and maximum performance, factors which include parameters such as material and component costs, assembly costs, maintenance cost and reliability. Fig. 5 illustrates the comparative costs of various WECS types and provides an indication to why stall regulated,induction generator, fixed speed machines seem to be most popular. Although there is bound to be some strong difference in opinion on this information, particularly with designers of very large machines (500 kW), the majority of manufacturers of WECS for grid application are overwhelmingly in agreement.

The predeliction of designers for fixed speed induction machines simplifies greatly the technology and equipment required to make connection of the WECS to utility lines. Figure illustrates the typical connection of a 500 kW machine which employes two 250 kW induction generators and associated power factor correcting capacitors.

3. INTERCONNECTION ISSUES

The obvious concerns of utilities and WECS developers in regard to grid interconnection are to safety, performance, and cost issues. Generally the specific issues under these headings are:

i. Safety

The most often stated issue regarding safety is the concern that the WECS be quickly disconnected from the grid in the event of an interruption of grid power. Safety of utility workers, customers, and connected equipment must be ensured. To reach this goal approved and tested control and protection equipment must be incorporated to ensure that the WECS will not energize a faulted line.

As well there is the requirement that the WECS itself be safely designed and operated to minimize risk to life and property at WECS installations.

ii. Performance

There are many performance issues that must be addressed. The principal concerns in no particular order are:

(a) Power Quality - The variable nature of the wind introduces large and relatively rapid fluctuations in power output of almost all wind turbines. These fluctuations can be expected to be present except in cases where storage devices or very elaborate control mechanisms are used to levelize power output. On many machines excursions of up to 100% or more of rated power may be expected within a few seconds. Large VAWTS may produce power that fluctuates cyclically twice for each revolution of the rotor. To ensure that undesirable variations in voltage and frequency to not exceed allowable limits it is necessary to provide the WECS with controls to limit variations or to switch the machines out of the grid circuit.

Harmonic power and disturbances that may distort waveform and produce other undersirable effects must be limited. This problem is of most concern where solid state inverters are used to interface with the grid. There is also a risk of that high frequency electromagnetic interference (EMI) and telephone influence factor (TIF) may be created by some inverter systems. EMI and TIF on transmission lines can of course be troublesome to radio reception and telephone communication over a wide area.

(b) Power Factor - Because of the preponderance of induction generators in WECS systems there is obvious concern that existing generation and distribution systems will have to contribute high levels of reactive power. The reactive power is required to provide the magnetizing flux for the generator. The obvious solution of adding capacitors at the WECS terminals is effective but must be performed by careful design to avoid serious voltage transient problems.

(c) Voltage Transients - Because of the inductive reactance of WECS generators there is possibility of large inductive voltage surges during disconnect. These surges can be potentially damaging to both utility and WECS equipment.

(d) Stability and Control - Although WECS because of their randomly variable power output are often considered as no more than negative load, there is potential when WECS capacity is a large proportion of the load, that other generation sources may be effected thus affecting efficiency, maintenance and other plant parameters. Little experience has yet been obtained in this regard.

iii. Cost

Issues related to cost are associated with the requirement for special or additional protection, metering, control and

monitoring equipment necessary to safely and effectively operate WECS equipment as a component of the grid supply. Where utilities wish to optimize the total system performance by scheduling other generators, it is necessary to have continuous indication of WECS performance if the WECS is to be a significant portion of the supply at any time.

4. INTERCONNECTION TECHNOLOGY

None of the interconnection issues described in the foregoing are without solution. The governing factor is usually cost and who should bear it. In general the approach by both WECS and utility designers has been to tend toward error on the safe side and thus provide a fair margin for safety.

In reference to the issues raised in the previous sections, methods, equipment and practices used to eliminate safety and performance hazards are as outlined in the following.

1. Safety

The hazard that a WECS will remain on line following a fault or outage situation on a grid has been effectively eliminated by the use of several control and sensing devices to ensure disconnect, shut down, and lock out of the WECS if a fault occurs. These controllers provide input to the WECS central control and usually trip the mains contactor or circuit breaker when a fault condition arises.

Generally, although each system design may have either fewer or additional requirements the following sensors and controls or their equivalents are often used.

(a) frequency band sensor - typically set -1 Hz, +2 Hz
(b) voltage band sensor - typically set 105 V - 130 V
(c) loss of phase sensor
(d) phase sequence sensor
(e) reverse power sensor
(f) over current sensor
(g) winding temperature sensor
(h) gearbox temperature sensor
(i) vibration sensor
(j) icing detector
(k) rotor speed sensor
(l) wind speed sensor
(m) wind direction sensor

The number of sensors used or desired is dependent upon WECS design characteristics. For example if the machine can remain excited with no external source then more controls are necessary to ensure that disconnect occurs. Most controls serve a dual role and protect the WECS equipment as well as the utility distribution system.

11. Performance

The combined performance of wind turbines and utility grids will depend to a great extent upon relative capacity and power rating values of the wind turbine(s) and the grid to which they are connected.

Concerns regarding voltage stability, frequency stability, flicker, and ripple become greater when WECS capacity becomes a significant proportion of the total capacity on the grid such as may occur in a remote community with a small diesel electric plant or when a large WECS installation is situated at the end of a long distribution line with high impendence and poor regulation. There are several methods to overcome performance problems in such instances. They may however add substantial cost to the WECS system. Some of the control techniques considered appropriate for this purpose are:

(a) WECS generator control
(b) utility load following control
(c) dump load into thermal storage
(d) load management

Each of these have certain merits and disadvantages. WECS generation control is generally a very expensive alternative. Variable pitch rotors and excitation controls on synchronous generators add significant cost to a WECS. Utility load following controls add extra cost to utility operation and may affect plant efficiency and generation scheduling. Dump load controllers are a low cost means of levelizing load but are practical only when economic use may be made of the dump energy. Load management is often the most attractive means of levelizing load but requires a willingness by the utility and its customers to accept interruptability of certain loads.

Power factor control to reduce or correct reactive power levels in utility distribution lines can be accomplished with the addition of capacitors to the generator. Usually correction is only required on large WECS with induction generators. It is important to realize when designing the correction system that over correction can create a hazardous condition. Under normal conditions an induction generator cannot remain excited and will cease generation almost instantly when disconnected from the utility. With the addition of capacitors across its terminals an induction generator may be able to obtain excitation from the capacitors and continue to generate into whatever curcuits are connected to it. Careful selection of capacitor size, usually that sufficient to correct power factor to about 0.9 will reduce this problem to manageable levels. Improper selection of capacitors can also cause hazardous voltage and torque surges on disconnect that may damage equipment. Ref. 1 provides a good description of the induction generator power factor correction technique and self excitation problem.

5. INTERCONNECTION EXPERIENCE

Of the thousands of wind turbines now connected to utility grids around the world there have been virtually no reports of serious accident or damage affecting utility grids. Although in the beginning there were certain reservation and even mild paranoia regarding the connection of wind turbines to electric grids, most of their concerns have now been resolved. Generally the special problems created by the introduction of WECS and large induction generators to the utility scene have been dealt with effectively using existing technology and equipment.

Standards have now been developed in many jurisdictions that provide WECS developers and utilities with requirements and guidelines for safe practice in the design and selection of interconnection systems. Many utilities also have developed procedures and specifications for interconnection of wind turbines and other small power producers to their grids. In Canada these are still in an early stage of development and will no doubt continue to evolve.

CSA Standard F418-M1986 ("Wind Energy Conversion System (WECS) Interconnect to Electric Utility") and CEA Research Report 340USOA ("Utility Policy on Co-generation and Small Power Production") provide current requirements for interconnection in Canada. Both of these documents are first editions.

Figures 6 and 7 illustrate two systems currently installed in Canada which although designed before standards were available in Canada generally conform to the current standards. Although all of these systems have suffered WECS side breakdowns and have experienced many utility outages, no damage or accident has occured related to the interconnection.

6. CONCLUSION

WECS integradation with electric utilities poses no technical, safety or performance problems which cannot be easily solved with existing technology and equipment. Experience to date has confirmed this situation and is enabling the design of more cost effective systems. Standards and policies have been developed that, although in first edition form, are serving the utilities and industry. These documents have high value to both WECS industry and the utilities. They will continue to do so only if they are used, reviewed and modified to encompass changing technology and requirements.

7. ACKNOWLEDGEMENTS

The Institute of Man and Resources receives financial assistance from the Department of Energy, Mines and Resources, Solar Energy Development Program to provide assistance and information to the Canadian wind energy industry and others interested in wind energy application.

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APPENDIX F

Appendix F

Final 31/8/89

International Energy Agency
Wind Energy Systems
Annex VII, Task B

Description and Performance of Wind/Diesel Systems:
Chapter 8 - Installation and Operation of Wind/Diesel Systems

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March, 1989

8.0 INSTALLATION AND OPERATION OF WIND/DIESEL SYSTEMS

8.1 Background

Wind/diesel systems by virtue of their capital, operational, and maintenance costs will most often be considered for placement in remote, isolated and poorly accessible regions of the world where power from conventional large or national electricity grids is not available. In most instances where wind/diesel electrical generation systems are contemplated there will also be fewer human, technical, and physical resources available to design, build, install, operate, and maintain the system. Any combination of these circumstances require that special emphasis regarding characteristics of resources available be given to design of the system and planning for subsequent installation, operation, and maintenance.

Some of the principal matters or issues that must be considered and resolved by potential installers and operators are outlined in the sections that follow. The subjects have been organized more or less in the order that events will proceed during realization of a project. Because of the potentially very wide range of project size, configuration, and site conditions, variable weight based on similar experience and solicited advice of experts should be given by the developer to each item.

8.2 Installation

8.2.1 Installation Planning

Once a wind/diesel system has been selected, designed and approved for installation at a site the process of installation can be commenced. When developing a plan or schedule for any

construction project consideration should be given to possible delays resulting from weather, transportation, availability of tools, and availability of equipment and labour. A documented work plan clearly indicating the most critical path and logical sequence of events should be adopted, followed and adapted as necessary to complete the work in the most proficient manner.

An essential stage of the plan if the system is to be installed in a remote location is to confirm system operation and completeness prior to shipment. This should involve either or both prototype testing and a commissioning test of a completely assembled system with an identical or simulated wind turbine and load characteristics of the installation site.

8.2.2 Transportation

Transportation of wind/diesel equipment and components will often involve the use of nonconventional means of packaging, handling and transport if the destination is remote and not served by conventional rail, truck, ship and air carriers. Means such as barges, heavy chartered air transport, helicopter, and various over land hauling methods and combinations thereof, may be necessary to deliver the equipment to the installation site.

Scheduling of transport relative to other stages and phases of a project is often critical because of long intervals between available shipping dates. These long intervals are caused by circumstances of weather and seasonal climate conditions, carrier space, carrier demand and requirements for special or unusual transport and handling equipment. For these reasons as well it is often necessary to reserve and guarantee space utilization well in advance of actual transport. It is also recommended that access to the site with all equipment and materials be confirmed.

8.2.3 Insurance

It is the shippers responsibility to obtain insurance against loss or damage of equipment and to confirm that the carrier is able to obtain insurance to protect against loss or damage to equipment while within his care and control.

8.2.4 Packaging

Packaging of equipment for shipment may often require special consideration in regard to weather, environmental and mechanical conditions during transport. If equipment is to be stored or left in unsecured marshalling areas special consideration should be given to packaging which prevents tampering and pilferage of parts. An inspection of the equipment should be made at destination and responsibility for further handling, storage and installation transferred accordingly.

8.2.5 Handling

In many sites or communities where wind/diesel systems are to be installed there are often few resources for local handling and surface transport or shifting of the equipment to the actual installation site(s). The carrier often is only capable of off loading immediately adjacent to the transport equipment.

The developer must then consider carefully the size and weight of components in context of handling and transport at destination.

8.2.6 Development Permits

Permits to build structures and install equipment such as wind turbines will often be required by national, regional, municipal or community councils. The developer of the project is usually responsible to determine which permits are necessary and to obtain them. It is advisable to complete this activity prior to committment to a project. In many instances it may also be necessary to show evidence that no adverse environmental, safety or nuisance effects will be caused by the planned project on the site selected.

8.2.7 Construction

Generally wind/diesel systems will differ widely in context of the construction activity necessary to complete installation. The principal construction related activities for a project or task can, however, usually be described by combination of the following construction or installations activity.

1. mass foundations
2. pilings and piers
3. soil anchors
4. slab foundations
5. on site buildings
6. prefabricated structures
7. towers
8. wind turbines
9. underground cabling
10. distribution pole lines
11. access roads
12. surface drainage systems
13. fences
14. battery storage
15. electrical distribution systems
16. earthing or grounding system
17. electrical controls
18. meteorological towers
19. diesel electric generators
20. liquid fuel storage and distribution systems

21. fire protection systems
22. telecommunication systems
23. monitoring systems
24. lightning protection systems

Assuming that the equipment is appropriately designed and documented many of these tasks can be carried out with the same ease and using similar techniques to those used for construction and installation of similar equipment in conventional locations. Some others however may often require special consideration to site conditions and resources available. Often the design and subsequent installation of a system must consider the availability and cost of such resources as:

1. skilled tradesmen
2. construction labour
3. transport
4. electrical tools
5. mechanical tools
6. hoisting and lifting equipment
7. excavation equipment
8. drilling equipment
9. hauling equipment
10. lodging and food
11. building materials
12. water
13. cement powder
14. concrete aggregate
15. fuel
16. temporary heat and electricity

This list can be considered as a partial checklist for surveying resources when planning an installation.

8.2.8 Foundations

Foundations for wind turbines and other structures must be given special consideration in design and implementation of a project. They are the essential physical interface between the equipment and the actual site. Although foundation materials may be shipped or transported to the site with the equipment, they invariably must be constructed on site. It is evident then that at remote sites concrete structures will be exceedingly expensive if aggregate and water is not locally available and alternative foundation systems should be investigated.

Soil condition and quality will also influence choice of foundation type and can pose challenging design problems when combined with resource availability and weather and climatic conditions. This is particularly true for foundations for wind turbines which must withstand overturning and dynamic loads and where even minor movement can be a serious problem. Soil

conditions that will pose the greater problems are characterized by:

1. rain storms
2. surface water
3. swelling clay
4. seasonal frost action on soils
5. permafrost - particularly if in boulder, sand, clay matrix and in areas with an active seasonal thawing layer
6. peat bogs and boulder plains
7. sand
8. poorly drained clays with high frost penetration.
9. land slides

Under these conditions and where uncertainty of soil engineering data exists it is very prudent to seek expert advice and to be able to provide consultants with accurate specifications of loads and other requirements as necessary to design safe foundations at a minimum cost.

8.3 Assembly and Erection

8.3.1 Procedures and Techniques

Assembly and erection of equipment for wind/diesel systems should be specified during system design and such specifications must also consider the availability of equipment required on site to perform certain tasks. Depending upon the nature of the equipment to be assembled and erected the installer should consider the availability, capacity, cost and safety of using equipment such as:

1. large and small cranes
2. transport trucks
3. traction and earth moving machines
4. excavation machines
5. drilling and boring machines
6. concrete mixers
7. winches
8. welding and oxygen cutting apparatus
9. portable heaters
10. portable shelters
11. portable electric generators
12. mechanical tools

8.3.2 Assembly and Erection Personnel

Erection of wind turbines is a specialized construction activity and should be performed by trained and experienced persons using approved and documented techniques and procedures and proper and approved tools and equipment. Where it is

necessary to adapt procedures or tools and equipment because of site conditions or availability the installer should obtain engineering advice from a reliable source and the approval of the project manager or other responsible authority. As well the availability, capability, and skills of local workers and tradesmen should be determined.

8.3.3 Inspection and Standards

Upon completion of installation the developer should inform electrical, utility and industrial equipment safety inspectors with jurisdiction in the area for inspection and approval of the system.

8.3.4 Weather

Many of the most interesting locations for wind/diesel systems are in areas where weather, climate and related conditions may make work very difficult during certain seasons and the interval during which construction work is reasonably possible may be very short.

Examples of such situations are in Canada's high Arctic communities where only a few weeks in mid-summer are free of snow and freezing weather during which the ground has thawed so that cable burial, foundations and other and surface work may be performed easily. Light conditions are also optimal during long hours of daylight so that work may proceed to the limit of worker endurance. At this time, however, black flies, noseeams, and mosquitos can make life miserable for those working outdoors. For such areas a good insect repellent is essential. In equatorial areas high temperatures and humidity may contribute to low productivity of workers unaccustomed to such conditions. Rainy seasons may make transport and construction work slow and difficult.

8.4 Commissioning

After installation commissioning tests should be performed on major components, assemblies and the complete system. Results should be compared with those obtained during development tests. As a minimum requirement commissioning testing should include confirmation of correct operation and performance. Chapter 9, section 9.2 describes recommended commissioning in detail.

8.5 Operation and Maintenance

Wind/diesel power systems require high levels of competent maintenance to achieve reliable operation and anticipated life expectancy of the system. Failure to provide proper maintenance will result in frequent system or component failures or forced

outages and may lead to catastrophic failure of engines, generators, wind turbines, and associated equipment.

Proper operation and maintenance can only be carried out by qualified and trained personnel who are suitably equipped with tools, spare parts and other necessary resources. When establishing operational and maintenance infrastructure developers should consider the following.

8.6 Personnel Selection

Because wind/diesel systems may vary in capacity from a few kilowatts to several megawatts staffing requirements may accordingly vary from a part time technical operator/maintainer to a team of several such persons. In general, however, because of the relative similarity of the equipment it is desirable that all of the technical personnel be capable of performing the majority of operational, maintenance and repair activity. This policy although perhaps leading to some redundancy in capability will provide continuity in operation when staff turn-overs occur. Such turn-overs occur with higher frequency in remote and isolated areas and are a continual problem in supplying services in such locations.

Although special training in operation and maintenance of specific wind/diesel systems should be provided to personnel, they should be recruited as skilled tradesmen, technicians, or technologists with experience in the general area of electro-mechanical technology and with demonstrable ability to operate, maintain and diagnose or troubleshoot such systems as:

1. diesel engines
2. engine governors
3. mechanical drive components
4. electrical generators and controls
5. electrical motors and controls
6. programmable logic controllers
7. electrical switch gear and protection devices
8. hard wired electronic controls
9. electrical, electronic, and mechanical instrumentation devices

they should also be able to learn quickly to proficiently operate, maintain and diagnose or troubleshoot:

10. system operational faults
11. wind turbine generator systems
12. computerized data acquisition systems and instrumentation

8.7 Monitoring

System monitoring should be performed with an automated data acquisition system that measures and records system performance data on a continuous basis. Such systems are developing rapidly and are a very cost effective and efficient means of recording both technical and economic performance of power generation plants of all types and sizes. An online monitoring system can in fact be only a component of the overall system control and may be programmed to provide fault diagnosis as well. Smaller systems (10 kW) may not be able to justify the cost of continuous monitoring.

Monitoring systems should be configured to provide for high data sampling rates (0.1 - 1.0 Hz) and longer averaging intervals (10 min. - 1 hr.) to produce performance summaries. The system should monitor many aspects of system performance such as:

1. fuel consumption and rate
2. unit generation
3. loads
4. system voltage
5. system frequency
6. engine starting events
7. wind and climatic data
8. outages and system faults
9. operation of control and protection devices

The system should also be set up to record planned and unplanned maintenance activity and to flag or set alarms for maintenance required. The maintenance schedule is thus tied directly to system operation and performance.

8.8 Documentation

A complete "as built" current system engineering description and operational, maintenance, fault diagnosis and repair information should be provided in drawings and manuals.

8.9 Spare Parts

Sufficient spare parts and components should be stocked on site to enable full repair of all systems on short notice. Exceptions can be made for diesel engine main block and head assemblies and diesel generators. In multiple diesel generator installations reserve diesel generation capacity will usually protect against engine/generator forced outages. In single engine installations alternative emergency generation, storage and load shedding may be provided.

An inventory of spare parts should be maintained on the monitoring and data system.

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Description and Performance of Wind/Diesel Systems: Chapter 9 - System Testing, Commissioning and Monitoring

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9.0 SYSTEM TESTING, COMMISSIONING AND MONITORING

Developers and purchasers of wind/diesel systems for installation in remote and isolated locations must have a high level of confidence that the system will have high reliability and perform as claimed or specified. The degree by which this confidence can be confirmed will be influenced greatly by the verification of performance and reliability achieved through a rigorous and well documented testing and evaluation program carried out during system development, commissioning and subsequent operation of the system. As well as contributing to initial confidence such testing and ongoing monitoring will also contribute to longer and more reliable and efficient performance of the system throughout its lifetime.

9.1 Development Testing

Development testing is that series of testing activities carried out in the manufacturer's or supplier's shops and laboratories to fully evaluate the performance characteristics of each of the system components and assemblies under simulated end use conditions that reliably and realistically replicate those that the system will experience in the planned application. These conditions can include but not be limited to:

1. load and demand characteristics
2. wind variability and climatology
3. ambient temperatures
4. other natural events and environmental conditions (icing, bugs, snow, rain, salt air, etc.)
5. operator and maintenance schedules
6. component failures
7. normal and emergency operational routines.

Development testing should be thorough and not assume that the performance of complex combinations of components and systems can be accurately indicated by individual performance testing of the components. The final development test should be performed on a system that is complete or can be verified to be identical to that to be installed.

Development testing should lead logically to later commissioning testing in situ. A testing report should be provided with the equipment that describes the testing performed and results obtained. The report should describe fully the methodology of the testing and provide sufficient information to allow later confirmation or comparison of performance in the field during commissioning trials.

Calibration accuracy of transducers and other apparatus to be incorporated into the equipment for commissioning and operational monitoring should be confirmed during development testing.

9.2 Commissioning

Once a system has been installed and all preliminary component testing and calibration has been completed the complete system should be commissioned according to a commissioning trial program specified during system design. Although the commissioning trials may have to meet specific requirements of the customers or clients or their agents, the system should also be sufficiently tested by the developer to confirm performance and reliability prior to turning the system over to the operators.

The minimum acceptable general requirements for commissioning should include:

1. confirmation of operation of all wind turbine safety devices and system protection over a full range of load and wind speeds;

2. confirmation of wind turbine performance and availability during 400 hours of operation during which power output will exceed 50% of rated output for at least 100 hours and availability, exclusive of weather or atmospheric induced effects such as icing, will exceed 95% during which no manual intervention is required to reset or restart the system;

3. typical performance testing could require measurement and recording of
   - wind speed
   - ambient temperatures
   - wind turbine(s) power
   - diesel power and KVARS

- system voltage
- system frequency
- load power and KVARS
- diesel fuel consumption
- kWhr produced and supplied
- operating interval
- operation of control and protection alarms

4. confirmation of proper operation of all controls, communication, monitoring safety and alarm systems;

5. confirmation of diesel generation heat rates and fuel savings;

6. confirmation of proper operation of all load management, storage, dump load and frequency control equipment during all intended modes of operation;

7. the complete system should be tested to determine its response to perturbation in load and wind turbine input. These tests should determine system resonances and transient behaviour. Typical tests will involve measurement of the system response to step function load disturbances from 10% to full load and to sinusoidally varying loads of varying frequency and aplitude;

8. the system should also be tested to ensure safe and proper response or shut down resulting from failure, fault or forced outage of one or more of the generation sources. In installations with storage or load management features proper response should be confirmed and adjustments made to optimize performance; and

9. power quality parameters such as system power factor, frequency and voltage stability and duration, harmonic content, flikker and telephone interference factors should be measured under a range of operational conditions and confirmed to be within acceptable limits.

9.3 Monitoring

The data, information and observations obtained during operational monitoring of wind/diesel power supply systems are necessary to ensure ongoing performance and reliability. Ongoing monitoring and recording of operation, maintenance and performance of equipment is normal practice in conventional utility operation and is essential to good management and reliable operation of the plant. In remote locations, diesel generators in combination with wind turbines, storage systems and

sometimes sophisticated controls should be similarly or more intensively monitored. Also because of the often disperse location of the system components it will often be desirable to use fully automated instrumentation and data logging equipment. Frequently it will also be desirable to equip monitoring systems with modems, telecommunication and/or satellite communication systems to enable remote collection of data and to exercise control over the system.

9.3.1 Monitoring Strategy

Wind/diesel systems may differ widely in configuration and size dependent upon end use requirements and choices made by the designer to meet those requirements. The means and specific characteristics of monitoring systems may also vary significantly. However there should be some general strategies employed to enable comparison of performance with other systems or alternatives.

When developing the specific strategy for monitoring of a wind/diesel system the following matters should be considered to identify the parameters and factors to be measured and recorded.

1. Power Performance - wind turbine
   - diesel generator
   - storage

2. Meteorological Factors - wind speeds and distribution
   - direction
   - ambient temperature
   - icing, snow fall, hail, rain

3. Load - direct load pattern
   - dump load
   - storage

4. Fuel Consumption - total
   - per unit

5. Operation - diesel generation hours
   - no. starts
   - wind turbine hours
   - breaker actuation

6. Sampling Time

7. Averaging Interval

8. Operational Log

9. Maintenance Log - diesel engine temperature
   - diesel engine oil pressures

Modern data loggers enable accurate measurement or sampling of many parameters at frequent intervals. Small modular systems can measure and record 16 parameters at rates to once each second. Larger PC based systems can sample 64 or more points at rates exceeding 100 Hz. Most are capable of measuring 12 to 16 bit data and have on-board processing to compile averages and standard deviation and to perform other processing and data classification routines such as:

1. binning for histogram and power performance
2. recording maximum and minimum events
3. setting alarms and
4. providing outputs for control purposes.

Measurements for monitoring purposes are most useful if compiled and stored in a time series for latter processing to produce performance summary reports including charts and diagrams.

Most of the data loggers may be communicated with by modem or telemetry and may be interrogated and programmed remotely making comprehensive monitoring programs inexpensive and practical. Systems which have a high speed or burst mode of operation to monitor a few selected parameters on demand are very useful for carrying out fault analysis of remotely located systems. Systems with built in memory capacity of about 16 K with expansion capability to 64 K and up are desirable. Most such systems have facilities to enable retrieval of data by modem to a PC computer and/or locally by magnetic tape or removable EPROMS. This type of system should always be considered since it offers such efficient means of investigating performance and diagnosing operation problems. One modest PC based computer can be used to communicate with and process data from several such systems.

9.3.2 Recommended Specifications

Data logging equipment and associated hardware should have a combined accuracy target of 1% - 5% or better and have 8 bit resolution. Most currently available systems are now 12 or 16 bit making good resolution easy.

Maintaining calibration accuracy and precision of transducers, sensors and instruments in the field is one of the greatest challenges to efficient monitoring of systems and one that must not be overlooked. Systems and devices that are particularly prone to deterioration, wear and damage due to normal operational events and weather conditions should be paired to allow for comparison and faults identification.

6.13 Electrical Safety

Electrical safety of wind/diesel generating systems must be confirmed to meet the requirements of established standards and codes for the safety of consumers, the public and operators. Codes and standards may be both those adopted and legislated by government and regulatory groups and those adopted by utilities and power generation authorities for their specific use.

It is the responsibility of the system designer to design and select safety and protection systems, devices and components and their application to insure the safety of the system.

Specific requirements for safety will vary from place to place and upon the nature and scope of the application. Specific examples of wind/diesel applications with varying safety requirements are:

1. Integration of a wind turbine with an existing small diesel grid or utility by an independent developer.

   The developer will be required to demonstrate that the wind turbine meets national wind turbine safety codes and that the electrical interconnection is safe and meets the requirements of the utility and state, province or country electrical safety codes.

2. Integration of a wind turbine with an existing small diesel grid or utility by the utility.

   The utility will apply internal codes and practices to insure that the equipment conforms. Other agencies or groups may require that the wind turbine meet safety standards if there is indication that safety of the public may be affected by installation and operation of the wind turbine.

3. Construction of a new wind/diesel plant in a previously unserviced area.

   The designer and developer should be able to demonstrate that each component of the system is suitably designed and applied in the system and that the components meet accepted safety codes for operation under the conditions intended.

In each case the successful completion of commissioning tests (See Chapter 9, section 9.2) under real and simulated fault conditions is a mandatory condition of acceptance and conformance to safety standards.